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A Crash Testing Evaluation to Prevent Injuries and Fatalities by Mitigating Vehicle Windscreen Spearing Risk from Road Signs

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Key Findings

- Sightboards installed at rural T-intersections are a potential hazard for motorists.
- Sight boards spearing through vehicle windscreens are found as a common road safety issue for both New South Wales and Queensland.
- An innovative research program was undertaken to develop a simple and low cost treatment with the aim of preventing penetration of the sign into the occupant space.
- This treatment can also be applied to any existing signs and new designs at T- intersections to improve road safety.

Abstract

Fatal incidents have occurred in Queensland and New South Wales involving sight boards spearing through vehicle windscreens. These crashes occurred at rural T-intersections where the impacting vehicle was travelling at high speed on the continuing carriageway. An innovative research program was undertaken to test various end treatments with the aim of preventing penetration of the sign into the occupant space. The research outcome sought was a low cost end treatment that could be applied to both new sign designs and existing signs. The testing program involved ten crashes at 100km/h with both four wheel drive vehicles and light passenger vehicles. The research showed that windscreen penetration could be prevented by utilising cost effective treatments.

Keywords

Crash Testing, Road Signs, Windscreen Spearing, Crash Reconstruction, T-intersections, Innovative Treatment

Introduction

A collision with a road sign is one of many potential hazards motorists are exposed to when driving on NSW roads. Road signs are struck relatively infrequently in terms of all crashes that occur on NSW roads; however, 43 fatal and 511 serious injury crashes involved a first or second impact with road signs over the six-year period, 2010 – 2015. This comes at a time when the NSW and QLD road toll is on the rise, with an increase of 14% and 9% at the close of 2015 on 2014 figures (BITRE, 2016). This type of collision has the potential to result in a fatal or serious injury (FSI) of vehicle occupants and riders.

Transport for NSW and Queensland Department of Transport supports the Safe Systems approach to road safety, and so action must be taken to reduce both the likelihood of a crash occurring and the severity of a crash should it occur. Transport for NSW has also shown a strong commitment to road safety, typified by programs such as the ‘Towards Zero’ campaign, which treats any fatality or serious injury on our roads as unacceptable (TfNSW, 2016).

In NSW from 2010 to 2015, two fatalities were recorded that have resulted from road signs spearing the impacting vehicles. In Queensland three serious crashes were recorded over the same period resulting in two fatalities and one serious injury. Although the crash data does not indicate this to be a particularly common incident, a review of these crashes identifies a number of factors that suggest a large exposure to the risk. These include the type of crash – run-off-road to the left, the impacting sign – intersection ‘sight boards’ on rural roads with higher (≥ 80 km/h) speed limits, and the type of impacting vehicle – mainly, but not exclusively, 4WD vehicles. These crashes occurred at T-intersections where the impacting vehicle was travelling at high speed on the continuing carriageway.

The sight boards are provided to give clear warning to traffic approaching the intersection from the terminating leg. However the existence of a sign may not be obvious to through traffic as its view of the sign consists only of a few sign posts and the edge of a thin sheet metal sign. With the large setback distance, it is not anticipated that signs of this type would present a hazard to traffic. It was thought that these signs were safe as the most likely impact scenario would be traffic impacting squarely from the terminating leg. The sign posts and the aluminum sign face are frangible.

The distance from the road surface to the bottom of the sign is variable as it can depend on the environment (rural or urban), vertical alignment geometry of the approaching terminating leg and how quickly the roadside embankment tapers away from the road. The Australian Standard for Manual of Uniform Traffic Control Devices (AS 1742.2-2009) limits the mounting height of signs not to be less than 1.5 m above the nearest edge of the travel way for visibility under headlight illumination at night in rural and a minimum of 2m above the top of the kerb to prevent obstruction to pedestrian and parked vehicles in urban environments.

For a particular crash involving a fatality, the road terrain was flat and the through leg had a slight bend. The distance from the road surface to the bottom of the sign was 1500mm. The vehicle involved was a four wheel drive and the distance from the road surface to the engine bonnet surface was approximately 1500mm. The traffic sign speared through the windscreen and entered the occupant space — refer to Figure 1. Despite the sign being installed according to the required standard, it was struck in such a way that it became a road side hazard, penetrated the vehicle and possibly injured the occupant - an unintended consequence of the design and placement. Moreover, end on crashes with signs set at a lower height showed that they have the ability to slice and spear through the body panels of motor vehicles. Early in 2016, Queensland Department of Transport and Main Roads and Transport for New South Wales began a joint research program into the issue of end on collisions with sight boards. The project team drew upon input from a range of specialists from both agencies and industries in Queensland and New South Wales.

The danger associated with end-on crashed with road signs has only recently come to the attention of road agencies. While these road traffic signs are frangible, their end-on



Figure 1. Sign spearing incident

impact directly with a vehicle windscreen is an unforeseen event. There is no review of any literature can be found under this topic.

For streamlining purposes other Australian state and territory road authorities were not involved in the project. It was reasoned that if this issue was evident in two large Australian states then the issue was likely to occur in other states as the road traffic sign designs are similar. The current practice is to share learnings from research projects with all Australian and New Zealand jurisdictions through Austroads.

Method

Between February 2016 and May 2017, ten vehicle crash-tests were conducted at the Roads and Maritime Services Crashlab in New South Wales. The research program utilised various cost effective treatments which could be retrofitted to existing high-risk signs. The approach was that any cost effective end treatment adopted should preferably be applicable to future new sign installations. A number of different sign sizes were also tested. The treatments were designed so that they could be performed in the field and were critically examined for practicality, value for money and crash outcomes. The ten crash tests were conducted using two vehicle types — a small passenger vehicle (Daihatsu Charade) and a 4WD (Nissan Patrol). Various sign sizes and arrangements were crash tested with different treatments (summarised in Table 1) with all tests conducted at a collision speed of 100 km/h.

Before the signs were modified a base line test was performed which had no treatment. This was followed by a number of tests with a progressive range of treatments. As the testing progressed, a knowledge base was built. This helped converging the design treatments for subsequent tests.

Table 1. Summary of crash tests

Test#	Treatment	Sign width (mm)	Sign depth (mm)	Posts	Post size (mm)	Rail type	Rivet type	Vehicle type	Windscreen penetration
Test 1	Baseline test - No Treatment	4000	400	4	50NB	Continuous	Pop rivets	4WD	YES
Test 2	Aluminium wrap sign end	4000	400	4	50NB	Continuous	Henrob rivets	4WD	YES
Test 3	Leading edge tethered - 5mm cable	4000	400	4	50NB	Cut	Pop rivets	4WD	NO
Test 4	Leading edge tethered - Flat strap	6000	600	4	65NB	Cut	Pop rivets	4WD	NO
Test 5	Leading edge tethered - HD clamp	3200	400	3	50NB	Cut	Henrob rivets	4WD	NO
Test 6	Flat steel clamp connection with Henrob Rivets	3200	400	3	50NB	Cut	Henrob rivets	Passenger vehicle	NO
Test 7	Leading edge tethered - HD clamp	6400	800	6	65NB	Continuous	Pop rivets	Passenger vehicle	NO
		4112	856						
		2633	976	2	80NB				
Test 8	Leading edge tethered - HD clamp	3200	400	3	50NB	Continuous	Henrob rivets	4WD	NO
Test 9	Leading edge tethered - HD clamp	3200	400	3	50NB	Continuous	Henrob rivets	4WD	NO
Test 10	Leading edge tethered - HD clamp	3200	400	3	50NB	Continuous	Henrob rivets	Passenger vehicle	NO

The testing was performed in a controlled manner with an instrumented vehicle and all crashes were captured on high speed video from various angles. In the past, Roads and Maritime Services Crashlab had crashed passenger vehicles into a range of obstacles. However they had never undertaken crash testing of this type before and it is believed to be the first of its kind in the world. The testing allowed the dynamics of crashes to be explored in detail and consequently the development of various sign treatments. The Crashlab provided a full technical report and high speed videos of each crash.

Sign Manufacturing Methods

To assist in understanding the various tests, refer to Table 1. In practice, signs have a range of sizes and manufacturing methods. The larger sign sizes have larger post diameters to overcome wind forces. In some sign designs the sign face and stiffener rails are held together with pop rivets and others Henrob rivets. A general description of the two riveting processes is as follows:

- Pop rivets — a hole is drilled through the rail and sign face and a pop rivet is installed. After installation, the pop rivet head is not flush with the surface but is raised. This manufacturing process is relatively slow. In all the crash tests involving pop rivets, the rivets fail very early in a crash. In some tests where the installed stiffener rails were cut with a saw, a number of pop rivets failed without any significant force being applied.
- Henrob rivets — Henrob rivets are a proprietary product utilising a solid stainless steel rivet with a countersunk head. Holes are not drilled in the Henrob process. The solid rivet is pushed through the sign face and stiffener rail with a hydraulic ram creating plastic deformation of the aluminum around the rivet. An anvil supports the stiffener rail on the opposite side and resists the installation force. During installation, the final step is for the rivet's leading cutting end and stiffener rail material to be deformed. This creates a splayed/mushroomed end which prevents rivet pullout. The rivets are supplied in a long plastic strip

from a magazine and can be installed as fast as the operator can maneuver the sign. The Henrob rivets are exceedingly strong and where they do fail it is typically by shearing a complete circular piece from road sign face. As the rivet material is stronger than the aluminum sign face or stiffener, the aluminum will fail in preference to the rivet. Installed Henrob rivets are flush with the sign face and can be sheeted over with the retroreflective sign material.

Results & Discussion

The pertinent points of the ten crash tests undertaken are discussed below.

Test 1 (baseline) - This was a baseline test of a standard sight board sign with a four post configuration. Upon impact the pop rivets easily sheared and the aluminium sign face crumpled but did not significantly enter the occupant space as it impacted the metal roof line above the windscreen. However, the Type 1 stiffener rails became detached and acted as spears. The top stiffener rail travelled over the top of the vehicle cabin. The bottom stiffener rail pierced the windscreen into the vehicle compartment in the general area of the passenger's head, continuing on past the seat, hitting the rear passenger side window. Figure 2 shows the damage

from the collision and the high likelihood of a fatal outcome to the occupant in the front passenger seat (and possibly the rear left hand side seat).

Test 2 (aluminium wrap sign end) — It became evident from Test 1 that not only does the sign face present a danger but also the aluminum stiffener rails. In Test 2 the front of the sign was encapsulated with 3mm aluminum sheet to tie the sign face and stiffener rails together as one unit. A deflector plate was incorporated into the bottom of this plate —refers to Figure 3.

The encapsulating plate added strength to the front of the sign which resulted in more damage to the vehicle roofline above the windscreen — refer to Figure 4. After Test 1 and 2, it was thought that the inertial forces were so significant that a windscreen could not develop enough resistance to deflect a sign over the vehicle. Even with the sign end having a special energy absorbing treatment and the impact area increased, windscreen damage was likely. When a crash occurs and the first post is bent out of the way, the remaining posts downstream hold the sign horizontally and provide restraining forces. Hence if a windscreen were to deflect a sign, it must overcome the sign's high inertial forces and the horizontal and vertical restraining forces provided by the intact posts.



Figure 2. Test 1 – sign layout & vehicle damage after crash



Figure 3. Test 2 - sign end reinforcement



Figure 4. Test 2 - significant vehicle damage



Figure 5. Test 3 – left - cut rails & stainless rope tether, right- successful crash deflection crash

The future research direction adopted was that the sign end must be prevented from impacting the windscreen. It was thought that some minor impact was tolerable as long as the sign face had been turned by approximately 90° which would present a large flat impact area to the windscreen and there would be no large concentrated inertial forces.

Test 3 (tethered with 5mm cable) — The leading edge of the sign was tethered to the first steel post with 5mm diameter stainless steel wire rope — refer to Figure 5. The stiffener rails were weakened at strategic points. The concept was for the post to pull the sign down and away from the windscreen. The test was a success but the field swaging of the stainless steel was considered to be time consuming. The field cutting of the stiffener rails was performed with a small battery powered circular saw fitted with an aluminum cutting blade. However it was difficult to saw cut the stiffener rails without cutting through the sign face was. Cutting the stiffener rails in this test and subsequent tests greatly facilitated the buckling of the sign during the crash.

Test 4 (tethered with flat strap & cut rails) — The sign face for this test was significantly larger (6 x 0.6m) hence 65NB posts were used — refer to Figure 6. In this test, the tethered design was refined by replacing the 5mm wire rope with 40mm x 3mm steel flat straps to simplify the field installation. As the sign was comprised of four separate



Figure 6. Test 4 - cut rails & flat straps

aluminum sheets, pull down straps were required to be fitted to each post. The stiffener rails were cut to facilitate failure. As a result of Test 3 learnings, a depth gauge was fitted to the circular saw which made cutting far simpler minimizing the damage to the sign face. This was the only test where the larger modified Type 2A stiffener rails were used.

Test 5 (heavy duty clamp & cut rails) — In the development of the project many ideas were explored. One simple approach that was suggested was to fasten the post directly to the sign. This idea was sidelined at the time over a concern that signs with large end cantilevers could pose a risk due to the downward slicing action during initial impact. In Test 5 the relative weak standard sign bracket was replaced with an off-the-shelf heavy duty clamp made from 40mm x 5mm flat steel – refer to Figures 7 & 8.

The clamp was fastened with two M10 bolts which passed through the sign face and stiffener rail. A large flat washer was placed under the head of the bolt to resist it being pulled through the sign face.

The clamp was fastened to the post with two self-drilling 14g x 20 screws which would act as shear restraints to



Figure 7. Test 5 onward – heavy duty clamps used



Figure 8. Test 5 - Shortened rails & HD anchored clamps

prevent longitudinal sliding. The cutting of the aluminum stiffener rails process was improved by lubricating the cutting blade with lanolin liquid lubricant.

Test 6 (heavy duty clamp & cut rails) — This test was identical to Test 5 with the exception that a small passenger vehicle was used in lieu of a four wheel drive – refer to Figure 9. Figure 8 and 9 both show the downward slicing action of the sign. A future consideration for low mounted traffic signs is to limit the sign end cantilever distance. The clamps successfully pulled the sign down to prevent impact with the windscreen. A significant drawback with the design approach in Tests 5 & 6 was it was difficult to install the sign while maintaining a flat front face due to shorter sections of stiffener rail. The heavy duty clamps gripped the posts tightly and would rotate the sign face as each clamping bolt was tightened. The sign installer had to be very diligent to ensure the finished sign face was acceptably flat. The performance of these signs in high wind conditions was an unknown.

Test 7 (heavy duty clamp & continuous rails) — The test involved a combination of large signs at a typical T intersection with intersection directional signs and a sight board — refer to Figure 10.

A component of the test was to witness the effect on a small car with crashing into larger diameter posts (65NB & 80NB) – refer to Figure 11. Heavy duty anchored clamps



Figure 10. Test 7 – large sign structures



Figure 9. Test 6 - Shortened rails & HD anchored clamps

were employed as per Tests 5 & 6. The design exception was that the longitudinal stiffener rails were not cut. Despite considerable vehicle damage the test was a success.

Test 8 (heavy duty clamp & continuous rails) — The learnings so far indicated that the sign end could be successfully deflected downward to prevent sign spearing into the occupant space. From studying the high speed video of the crashes it was felt that the two screws securing the heavy duty clamps to the posts sheared too early in the crash. If the screws were stronger they would allow a longer pull down time before failure.

For Test 8 these shear restraint screws were replaced with high tensile Taptite M8 x 20 hex head screws. These screws were self-tapping but a 7.3mm-diameter pilot hole had to be pre-drilled to accept the screw. Drilling a small diameter pilot hole was not considered to be a significant issue for field installation. The object behind the testing was to find solutions for both new signs and existing signs. For existing signs it was felt that the concept of a heavy duty clamp bolted through the sign face was a viable option. Although better performance would be gained through stronger shear screws.

However if the stiffener rails were fastened with Henrob rivets and with extra rivets in the vicinity of the posts then it may be possible to achieve a successful outcome without bolting through the sign face. From an aesthetics aspect, it would be preferable for a new installation not through bolt the sign face.

Test 8 was designed to test this scenario. The heavy duty clamp was fastened to the stiffener rail with the standard cup head bolts mounted in the groove in the rail — no though bolt was used. Cutting the stiffener rails were found to be too laborious in the field and for sign manufacturing hence continuous rails were used.

The purpose of this test was to confirm that heavy duty clamps fastened to stiffener rail would work in conjunction with the closer spaced Henrob rivets at the posts.

Although the sign did not penetrate the occupant space, Test 8 was not considered to be successful – refer to Figure 12. The high speed video showed the bolts and heavy duty



Figure 11. Test 7 – left-small vehicle on impact, right- large area signs & large posts

clamps could not generate enough force to prevent sliding along the stiffener rail. When a large axial and transverse force was applied to the cup head bolts, the channel shaped aluminum stiffener rail bent open allowing the bolt heads to escape. During the initial pulldown, the bottom edge of the sign face had sliced through the vehicle bonnet.

Once the bolts were pulled free of the stiffener rail, the sign continued to slice open the bonnet until it hit a strong bonnet cross member where it was forced to buckle. The additional Henrob rivets placed in the vicinity of the posts stiffened the sign further which worsened the situation.

Test 9 (Heavy duty clamp, continuous rails) — The same sign configuration and vehicle used in Test 8 was again used in Test 9. Notable points were:

- The heavy duty clamps were bolted through the sign with large diameter washers located under the hexagonal bolt heads on the sign face — refer to Figure 13.
- Two Taptite M8 x 20 hex head screws per clamp were again used.
- The standard spacing of Henrob rivets was adopted (~200mm centers) to streamline manufacturing.
- Type 1 stiffener rails were used.
- Heavy duty clamps were installed on all posts.



Figure 12. Test 8 – No through bolts and slicing of the bonnet

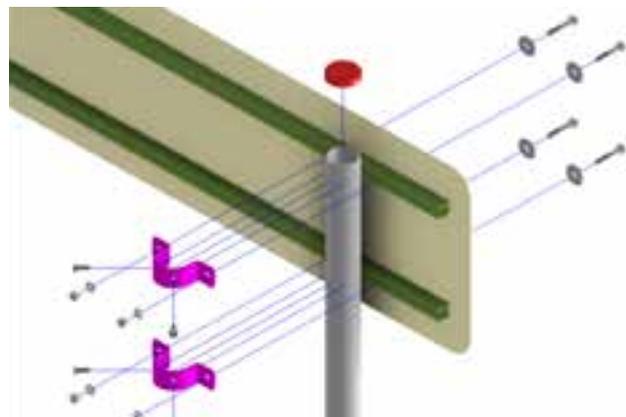


Figure 13. Test 9 - HD clamps & bolted through

Prior to Test 9, a sign manufacturer was consulted about the testing program and research findings so far. From a manufacturer's point of view, the installation procedure must be simplified. In the previous tests, the last post was fitted with the standard low strength clamps. In practice this could lead to the possibility that this clamp could be inadvertently fitted to the leading post. Hence to minimize the risk of incorrect installation, a safer solution is to make all clamps the same type. This has the added benefit that impacts from the other direction were also catered for although with much less probability of occurring.

This test was considered a success as the sign buckled at initial impact and was pulled down — refers to Figure 14.

Test 10 — Before the testing program could be declared a success, Test 10 had to confirm that the final design would work with both a large and small passenger vehicle. This test replicated Test 9 with the exception that the test vehicle was a small passenger car — refer to Figure 15. This test was considered a success with only minor windscreen cracks and no sign spearing through the windscreen. During the testing program some minor windscreen cracking occurred through unpredictable hits by deformed sign components.

Flexible road signs were investigated as an alternative solution in eliminating the potential of sign spearing under the above tested conditions. These signs offer little



Figure 14. Test 9 – successful pull down



Figure 15. Test 10 – successful use of HD clamps & bolted through design

resistance to the colliding object and thereby causing virtually no impact force to be imparted on the vehicle and its occupants or riders. A commercially available product has been tested and was found to require complete replacement after one collision. While this protected the vehicle occupants, the installed sign was prohibitively expensive. Its application would not address the vast number of existing signs that require treatment. Therefore the replacement of traffic signs with flexible “plastic” signs is not considered as an alternative approach.

Conclusion

The crash testing program has proven that both currently installed and new signs could be successfully treated with the use of heavy duty bolted clamps in combination with shear connectors. High speed vehicle crashes with both four wheel drives and small passenger vehicles have demonstrated that the signs can be prevented from entering the occupant space of the vehicle.

The findings of this research will be implemented through changes to traffic sign manuals in Queensland and New South Wales. The learnings will be disseminated to other road agencies through the Austroads Road Safety Task Force, national traffic engineering conferences and traffic

management industry groups. The additional cost of the treatment is considered to be minimal with huge benefits in reducing the cost of fatalities. Adopting the outputs of this new and innovative research will lead to a safer road environment for motorists.

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References

- BITRE 2016, Road Trauma Australia—Annual Summaries, Bureau of Infrastructure, Transport and Regional Economics. Retrieved from https://bitre.gov.au/publications/ongoing/files/Road_trauma_Australia_2015.pdf
- TfNSW 2016, Towards Zero, Transport for NSW. Retrieved from <http://www.towardszero.nsw.gov.au/>
- Australian Standard AS 1742.2—2009, Part 2: Traffic control devices for general use, Manual of uniform traffic control devices



Figure 16. Testing of flexible signs